LA-6711-MS
Informal Report

Special Distribution

Issued: February 1977

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CONTRACT W-7405-ENG. 36

This work was supported by the US Air Force Armament Laboratory (AFATL), Eglin AFB, Florida, under the US Energy Research and Development Administration Reimbursable Project R-441.

HAZARD CLASSIFICATION TEST OF MIXED-LOAD 30-mm GAU-8 AMMUNITION BY BONFIRE COOKOFF AND SYMPATHETIC DETONATION TESTING

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ABSTRACT

A hazard classification test of mixed-load (high explosive and armor-piercing) 30-mm GAU-8 ammunition was performed in October, 1976, for the U.S. Air Force Armament Laboratory (AFATL). Fragment pattern scoring following bonfire cookoff of 180 live rounds indicated 385 ft was the maximum distance any fragment was thrown by explosions of the ammunition. Small amounts of uranium aerosol dispersed by the bonfire were detected at three air samplers placed near the bonfire. In a separate test, sympathetic detonation of high explosive rounds in a container of mixed-load ammunition was tested by detonating a single round. No sympathetic detonation occurred.

I. INTRODUCTION

The U. S. Air Force Armament Laboratory (AFATL), Eglin Air Force Base, Florida, requested performance of a storage and handling hazard classification test of a 5:1 mix of armor-piercing incendiary (API) and high explosive incendiary (HEI) 30-mm ammunition designated GAU-8. This test, performed under bonfire conditions and known as a bonfire cookoff test,[1] was to be similar to a bonfire cookoff previously performed by the Los Alamos Scientific Laboratory (LASL) in 1975 on 180 rounds of API ammunition containing depleted uranium (DU).[2] Tests involving DU, which is considered as a radioactive material and toxic heavy metal,[3] have been performed at R-Site for many years. Temperature instrumentation and limited air sampling for DU

aerosol were to supplement the standard test requirements. Additionally, a sympathetic detonation test was performed to document the effect of detonating a single HEI round within a case of mixed ammunition. Both tests were performed under an interagency agreement between USERDA and AFATL.[4]

II. DESCRIPTION OF BONFIRE COOKOFF TEST PREPARATIONS AND SETUP

Overall test direction, site and test preparations, air sampling, sample analysis, test evaluation, and reporting were the responsibility of the Industrial Hygiene Group (H-5). Communications, site safety, squib firing, live shell disposal, and on-site supervision was provided by the Pin Diagnostics and Neutron Measurements Group (M-4). Meteorological support and site restoration were provided by the Environmental Studies Group (H-8) and photographic documentation by Graphic Arts (ISD-7).

Procedural guides were contained in the H-5 General Test Plan and M-4 SOP 11 "Explosive Burning Experiments" as revised to accommodate high explosive burning. The test location was R-Site, firing point E-F, the same location as the 1975 test.[2] R-Site was the largest cleared and reasonably level area available for this test and has a long history of tests involving explosives and uranium. Its distance from the main technical area and Los Alamos townsite (about 4.0 km) provided adequate safeguards relative to maximum uranium concentration if typical plume dispersion conditions for this time of year existed during the test.

The standard North Atlantic Treaty Organization (NATO) bonfire cookoff procedure calls for a 500-ft radius circle to be cleared for detailed fragment scoring.[1] The R-Site clearing is about half that size, requiring a compromise agreement between LASL and AFATL in which a 360° sector of 100-ft radius and a 180° sector of 400-ft radius received detailed scoring. The 100-ft-radius circle (360°) was scraped clean of all vegetation. Mowing and raking the semicircle to 400-ft radius provided an acceptable clearing for representative, if not total, pattern scoring. Scoring categories were: (1) API round (complete); (2) HEI round (complete); (3) API projectile; (4) HEI projectile; (5) shell base (thick section at bottom of the shell); and (6) fragment (any thin section of a shell separate from a shell base). Shell bases and fragments in the graded area (full circle from 30 to 100 ft) were located by azimuth (±1°) and distance from center (±1 ft) with tape and transit. In the semicircle from 100 to 400 ft, locations were logged with transit and level rod (stadia method) to the same accuracy.

The NATO procedure used by the U.S. Air Force for bonfire cookoff tests specified the general configuration of the stack and how it was to be ignited. The general requirements were (1) five cases of 30-mm ammunition (180 rounds) stacked in a 2-on-3 array and banded together by steel bands, (2) the ammunition placed on the platform 0.9 m (36 in) above ground-level supported by two columns of sand-filled ammunition cases, (3) kindling no larger than a two-by-four packed around the platform and ammunition to a thickness of at least 0.45 m (18 in) , (4) the stack soaked with 57 ℓ (15 gal) of diesel fuel, and (5) ignition of the stack on two sides by electrically operated squibs. This procedure was followed with the minor exception that two 208-ℓ (55-gal) drums were substituted for the ammunition cans to support the platform. The 1975 test air concentration estimates based on the Gaussian plume model were again applicable and provided an advance evaluation of potential off-site hazard.[2] Parameters entering the calculated estimates of air concentration were the DU release rate (estimated to be 16 g/s if 50% of all DU were aerosolized); source height (estimated to be 5 m); wind speed 3 m/s; and Pasquill's atmospheric stability category C, all similar to assumptions for the earlier test. Atmospheric category C (slightly unstable) represents a conservatively poor diffusion condition.[5] Mid-October, when the test was conducted, typically would have conditions providing a higher dispersion coefficient. Figure 1 presents concentration isopleths based on these parameters. The inner isopleth which

represents 10^{-4} g/m^3 lies very close to the nearest uncontrolled (also unpopulated) area, which was about 1830 m away from the test site. This indicated that the threshold limit value (TLV) for uranium, 2×10^{-4} g/m^3, would not be exceeded at that point.[6] This analysis provided ample conservatism, since the TLV represents an allowable 8-h/day, 5-day/wk exposure and the calculated concentration of 10^{-4} g/m^3 would be a short-duration, single-time exposure. Worst case calculations using lower wind velocity and neutral stability indicated the advisability of (1) providing respiratory protection for on-site test personnel and (2) postponing the test if wind velocity was below 3 m/s and high stability persisted.

To avoid performing the test under worst case conditions, weather conditions were observed several days before the test by continuously recording wind velocity and direction at R-Site. Free-lift balloons and smoke flares were released immediately prior to the test to indicate wind direction and probable rise characteristics of the smoke plume.

Full-time, real-time color movie documentation of the bonfire cookoff test was obtained from an observation point 510 m from the bonfire. Two cameras were operated approximately 25 min at 24 frames/s. Still photographs (black-and-white, color) were taken of various aspects of the test, including telephoto from the observation point and closeups of fragments and bonfire residues. Forty-seven color and 36 black-and-white photos for still documentation and the movie film have been sent to AFATL, Eglin Air Force Base.

Instrumentation for the bonfire cookoff test consisted of five high-volume air samplers located close to the bonfire and four thermocouples placed on the surfaces of the ammunition cans. Three open-face, high-volume air samplers approximately 6 m above the ground on pole-mounted platforms were operated at 0.0165 m^3/s. Large Whatman 41 filters (18 cm x 25 cm) collected the aerosol. Two other high-volume samplers (capacity 0.033 m^3/s) were located 0.9 m above the ground downwind of the bonfire. Figure 2 shows overall arrangement and locations of the stack and samplers. The pole-mounted samplers were arranged across the SW quadrant approximately 15 m (50 ft) from the center of the bonfire. The two 0.033 m^3/s samplers were 6 m behind these. This limited sampling program was not designed to quantitate the release and air concentration of uranium. It would only indicate that uranium was aerosolized during the test.

III. RESULTS AND DISCUSSION OF BONFIRE COOKOFF

A. Test Sequence and Temperature History

Wind velocity and direction were fairly steady in advance of the test, ranging from 2.5 to 4.5 m/s coming from the NE quadrant. Wind velocity dropped somewhat at test time and nearby office buildings and the observation point for the test were generally downwind of the bonfire. However, free-lift balloons released shortly before the scheduled test time remained generally south of these sites and exhibited consistently rapid rise. Acoustic sounder readings and pibal wind profiles taken at Occupational Health Lab 3350 m NE of the site also showed good mixing conditions. The decision was made to perform the test as scheduled. The events of the test are given in Table I. A notable difference between this test and the 1975 test was the much earlier occurrence of first report (shell case propellant or HEI projectile explosion) at 3 min 15 s vs 10 min in the 1975 test. A photograph of the bonfire midway through the burn is presented in Fig. 3.

The temperature recorder and air samplers were started at 1135 h and operated 69 min. Temperature history is summarized in Table II. Thermocouple 4 was located between two ammunition cases and the other thermocouples were taped to outside surfaces of ammunition cases. All four thermocouples initially responded properly, but the record indicated thermocouple 4 was disabled at 3 min 15 s after squib firing, coinciding with the first report. Peak temperatures and the temperature coinciding with the first report are given. Peak temperature was higher in this

TABLE I

BONFIRE COOKOFF EVENTS

Event	Time (min:sec)	Clock Time
Squibs fired	t = 0	1134
Started temp recorder and air samplers	+ 1:00	1135
First report[a]	+ 3:15	1137:15
High intensity reports	+ 4:15	1138:15
Reports ceased	+ 19:35	1153:35
Stopped temp recorder and air samplers	+ 69	1243
Bonfire approached	+ 75	1249
Water spray started	+ 80	1254
Fire out	+126	1340

[a]Propellant or HEI projectile explosion.

TABLE II

TEMPERATURE HISTORY

Thermo-couple	Location	Peak Temp °C	Time at Peak Temp (min:sec)	Temp (°C) at First Report
1	South end	905	6:40	805
2	North end	830	4:45	740
3	East side	995	5:10	760
4	Between cases	a	a	505

[a]Thermocouple failed to operate after 3:15, which was time of first report.

test than in the 1975 test (995°C vs 905°C). Indicated thermocouple temperatures, other than thermocouple 4, were fairly consistent at first report, ranging from 740-805°C. Indicated temperature rapidly decreased beginning 8-10 min after first report either because the thermocouples were disabled or were exposed to cooler gas after the kindling stack started settling. The grating did not sag in this test as it did in the 1975 test. The bonfire site following the test is shown in Fig. 4.

B. Test Observations and Pattern Scoring

Visual and photographic observations of complete round, projectile, shell base, and fragment locations within a 30-ft radius of the bonfire were made without scoring by distance and azimuth. Locations by distance and azimuth in the 30-100-ft range and 100-400-ft range are given in Figs. 5 and 6, respectively. Totals in several descriptive categories are given in Table III. Photographs of projectiles located in the 30-ft circle and from 30-100 ft are shown in Figs. 7 and 8, respectively. The following statements summarize these findings:

1. Approximately 85% of all API projectiles and 63% of HEI projectiles were within the 30-ft radius.
2. Two complete rounds were located outside the 30-ft radius at 32 and 39 ft.
3. Furthest API projectile was located at 89 ft.
4. Furthest fragment or base was located at 385 ft compared to 465 ft in the 1975 test.
5. Seven penetrators experienced visually detectable mass loss. Two of these penetrators lost 10-20% of their mass based on visual estimates; five lost 5-10%. This loss is much lower than observed in the 1975 test. The cause for reduced DU losses could be one or more of the following: (1) the bonfire had less kindling and did not maintain high temperature as long as the earlier test; (2) the grating did not sag and drop the ammunition cases into the high temperature region as it did in the 1975 test; or (3) the penetrators may be a different alloy, having come from a different manufacturer. The amount of kindling placed on the bonfire was not precisely measured for either test (test procedures do not require this), but it was estimated to be about the same in both cases.

The total number of shell bases and fragments located in three scored areas are given in Table IV. These values and 1975 test values compared very closely in total fragments and bases, although fewer were thrown beyond the 100-ft circle in this test (79 vs 112).

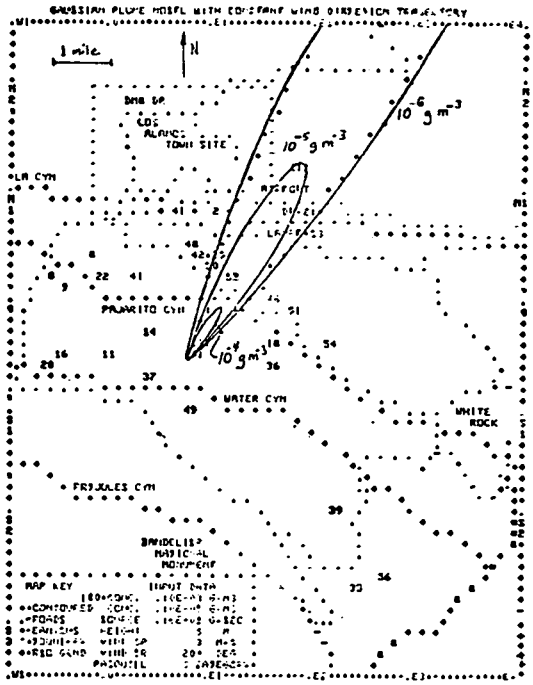

Fig. 1.
Results of Gaussian plume calculations for the nominal case.

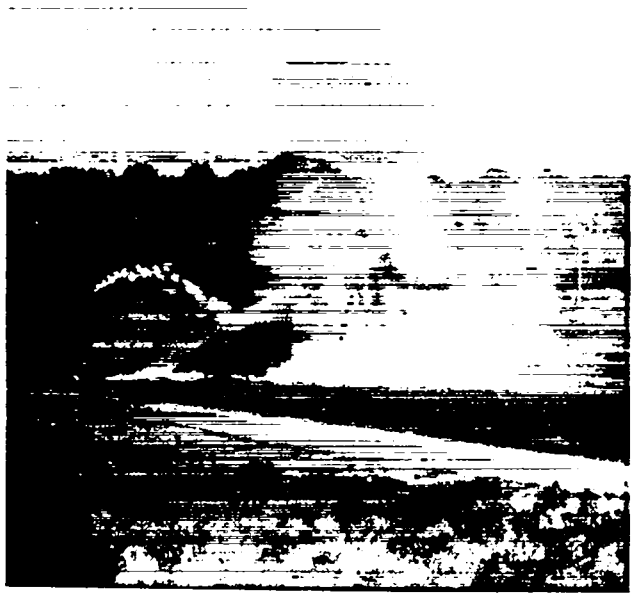

Fig. 3.
Telephoto of the bonfire midway through burn.

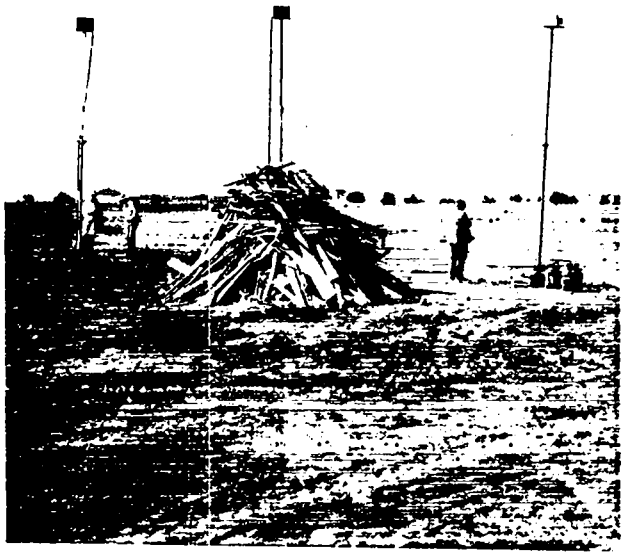

Fig. 2.
Overall arrangement of stack and samplers.

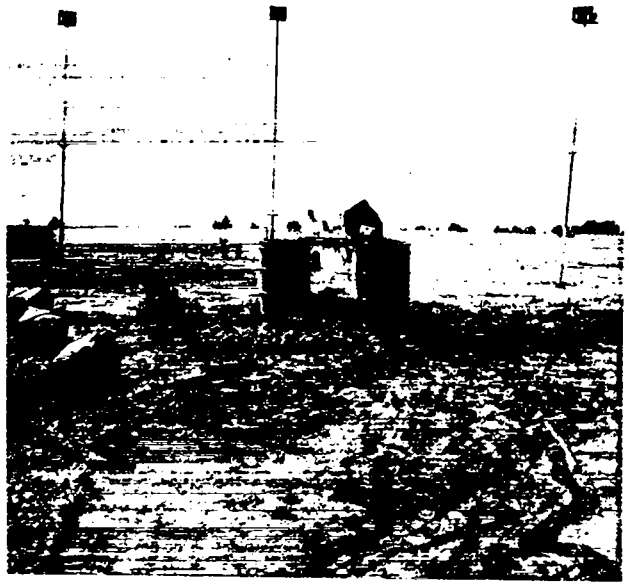

Fig. 4.
Bonfire site following the test.

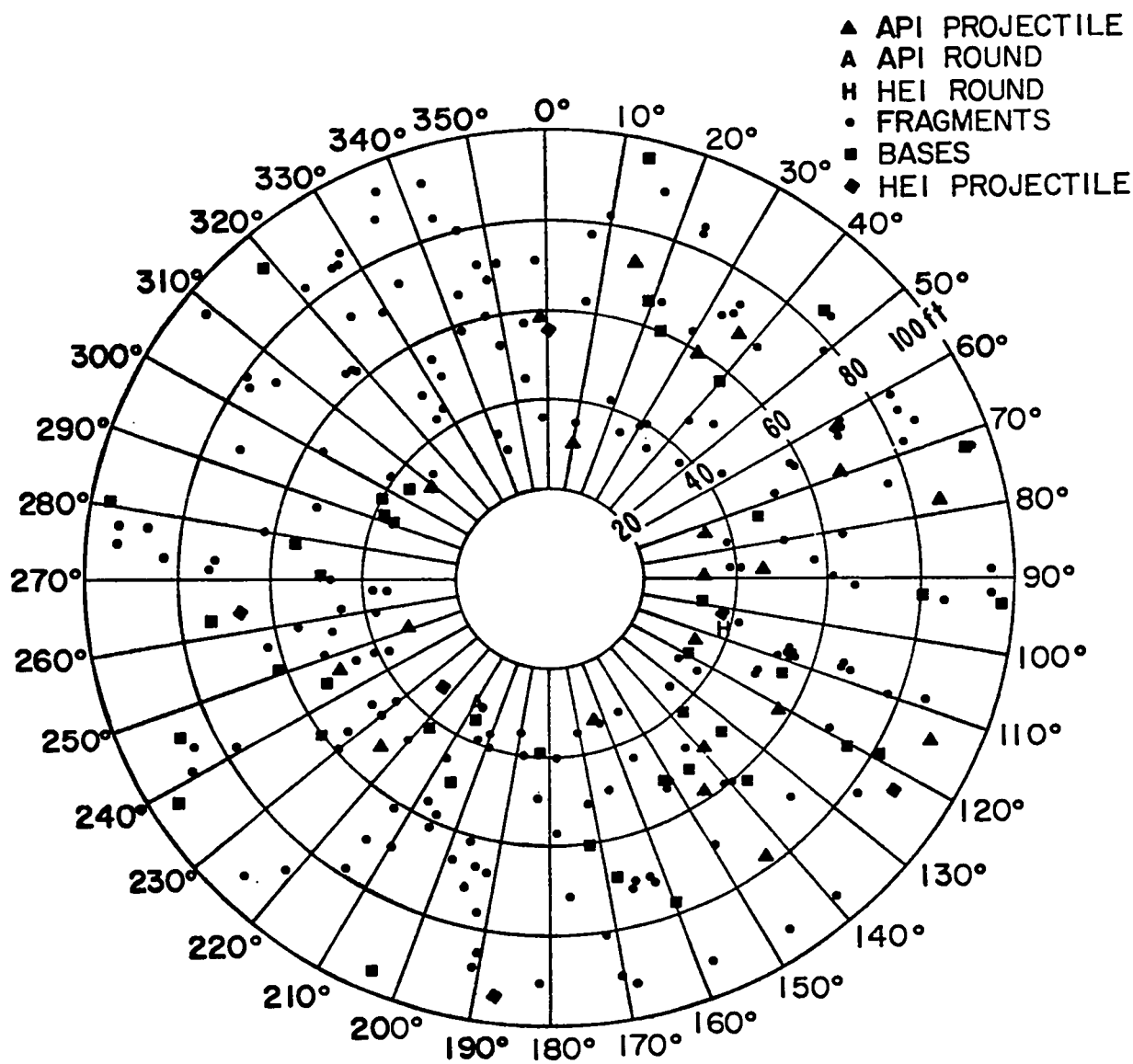

Fig. 5.
Pattern scoring of the 30- to 100-ft-radius circle.

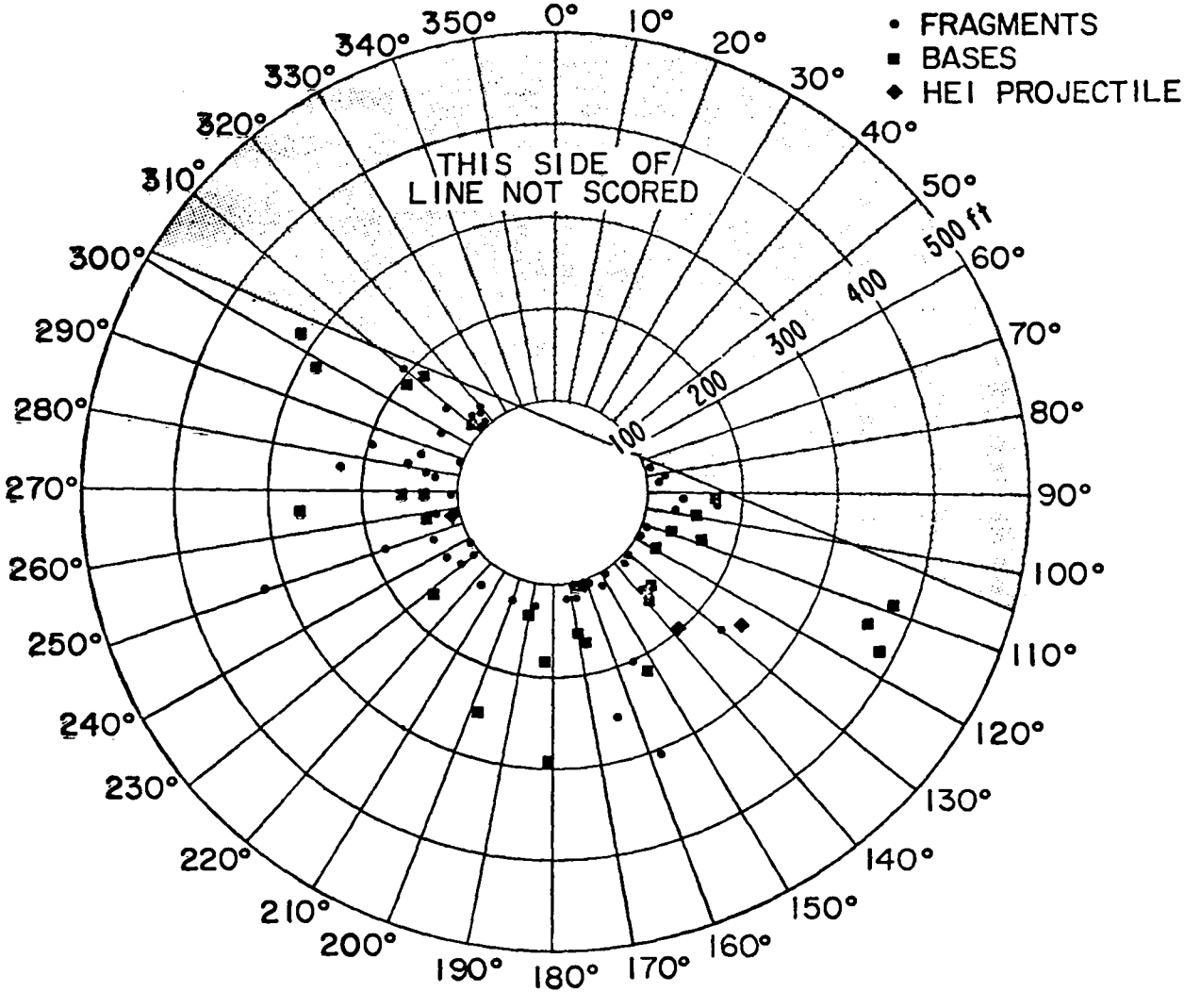

Fig. 6.
Pattern scoring of the 400-ft-radius circle.

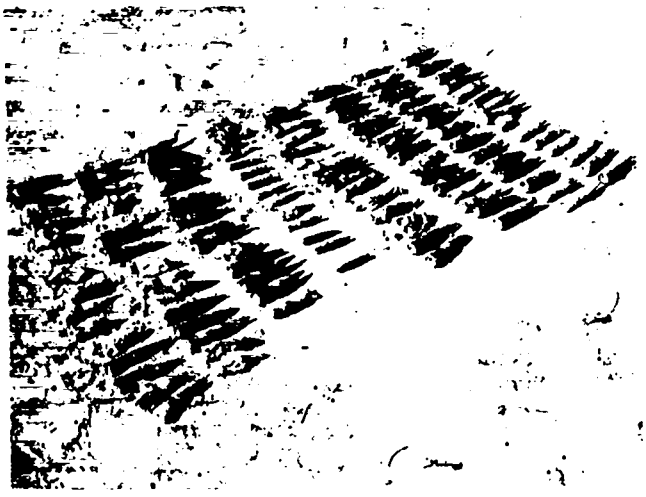

Fig. 7.
Projectiles located within 30-ft circle.

Fig. 8.
Projectiles located between 30- and 100-ft circles.

C. Air Sampling Results

Despite the apparently lower gross loss of DU from penetrators compared to the 1975 test, the limited objective of air sampling to detect DU aerosol was again realized when the three pole-mounted samplers showed positive indication of uranium. The results of mass determinations of uranium collected on the 18 cm x 25 cm Whatman 41 filters (Samples 1-5) are presented in Table V. Total aerosol mass and DU collected on the filters are included for comparison. Although differences in the sampling techniques prevented direct comparison with the 1975 test results, the DU fractions of total ash for this test were less than 10^{-2} of the 1975 test results. It should be emphasized that the sampling network was designed solely to confirm the presence of DU aerosol and did not provide a quantitative estimate of total DU released to the atmosphere.

Sample analysis was accomplished by wet ashing one-fourth of each Whatman 41 filter using concentrated nitric acid and hydrogen peroxide, dissolving the residues in 25 cm^3 of 6N hydrochloric acid, and analyzing for uranium. Samples were analyzed for uranium using a fluorophotometric method with sensitivity at about 0.1 μg.[7] This method is based on intense yellow-green fluorescence at 555 nm by uranium. Additional sensitivity to measure the values in Table V (0.04 μg) was obtained by extracting the uranium from the 25 cm^3 6N hydrochloric acid solution using 2 cm^3 of 5% triisooctylamine (TIOA) in xylene and measuring the uranium in a 0.2-cm^3 aliquot of the organic phase. Blanks and standard (spiked) samples were used to control the accuracy of the analysis.

The amounts of DU detected on Samples 1, 2, and 3 indicate mean air concentrations of 2.8 x 10^{-6}, 7.6 x 10^{-6}, and 4.2 x 10^{-6} mg/m^3, respectively, which are significantly above maximum concentrations of natural atmospheric uranium in this area, which ranged from 0.07 to 0.25 x 10^{-6} mg/m^3 during 1974 at five LASL technical area stations and at ten stations around the perimeter of the LASL complex.[8] Analysis of the data beyond the simple conclusion that a DU aerosol was present is not supportable, considering the limited number of data, different sampler heights and distances, and wind speed and direction variability.

TABLE III

SUMMARY OF PROJECTILES, PENETRATORS, AND COMPLETE ROUNDS RECOVERED AFTER BONFIRE COOKOFF TEST

Item Description	API	HEI
1. Located Within 30 ft		
Complete Rounds	9	1
Penetrators	119	NA[b]
Projectile w/fuse and explosive	NA	6[b]
Projectile w/explosive (no fuse)	NA	9[b]
Projectile (low order)[a]	NA	2[b]
Projectile (no explosive)	NA	3
2. Located between 30 ft and 100 ft		
Complete Rounds	1	1
Penetrators	21	NA
Projectiles	NA	7
3. Located between 100 ft and 400 ft		
Penetrators	0	NA
Projectiles	NA	3
Total	150	32[b]

[a]Low order--incomplete explosion of HE.

[b]This value may be in error. The total exceeds (by two) the number of HEI projectiles available. Two live projectiles from the 30-100-ft area were erroneously recounted in the within-30-ft category.

NA - Not applicable.

TABLE IV

SCORING TOTALS OF FRAGMENTS AND BASES

	1976		1975	
Distance	Fragments	Bases	Fragments	Bases
Under 30 ft	~ 112	~ 59	a	a
30-100 ft	188	41	163	33
100-400 ft	50	29	71	41
Total	350	129		

[a]Data not measured for under-30-ft circle.

TABLE V

URANIUM COLLECTED ON HIGH VOLUME SAMPLERS

Sampler	Uranium Mass (μg)	Total Mass (mg)	Sampler Location		
			Distance (m)	Height (m)	Azimuth
1	0.19	38.48	15	6.1	200°
2	0.52	44.35	15	6.1	260°
3	0.29	43.88	15	6.1	225°
4	0.04	39.05	21	0.9	240°
5	0.04	34.75	21	0.9	215°

[a]Data not measured for under-30-ft circle.

IV. SYMPATHETIC DETONATION TEST

The sympathetic detonation test was conducted in accordance with the general procedure described in a USAF hazard classification report for HEI ammunition[9] and following the Group M-4's standard operating procedure. The ammunition undergoing test consisted of a single shipping container of mixed 30-mm GAU-8 ammunition (6 HEI: 30 API). The container included one round that had been modified for static detonation.

Detonation wires were run through a hole in the bottom of the container and connected to a RP-2 detonator which was inserted into a modified M505A3PD fuse assembly. The photograph in Fig. 9 shows the general connection of the modified round; Fig. 10 shows the location of HEI rounds in the container. The modified round was placed two positions away from the centerline of the container.

By AFATL request, a pretest radiation survey was conducted using a Ludlum Model 14 portable survey instrument. Indicated gamma radiation levels were as follows:

Contact with container top	0.12 to 0.5 mr/h
Contact with container side	1.2 to 1.4 mr/h
Contact with container end	1.5 to 1.7 mr/h
30 cm from container side	0.7 mr/h

A similar survey following the test was waived. Prior to the test, the container was covered over with sandbags (38 to 46-cm thickness). Detonation was initiated without direct observation of the test site. Several reports after the initial detonation indicated shell case disruptions were caused by fire in the packing material. Figure 11 shows the aftermath of the test. None of the

Fig. 9.
Modified round and detonator.

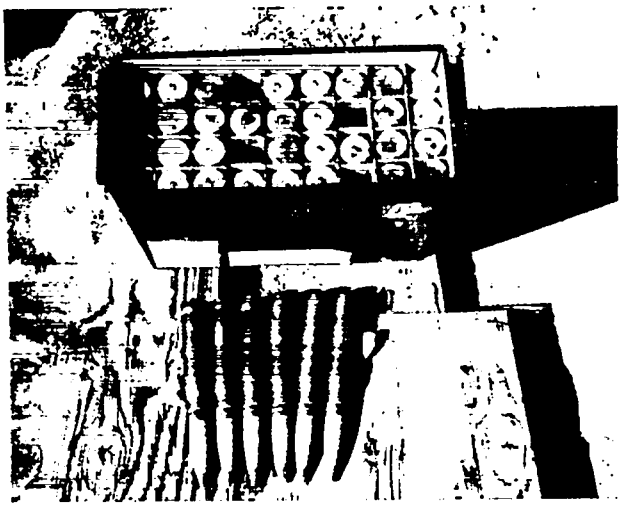

Fig. 10.
HEI rounds and locations.

Fig. 11.
Aftermath of sympathetic detonation test.

other five HEI rounds detonated sympathetically. Propellant in numerous other rounds apparently exploded at some time during the test.

V. SUMMARY

Results of the bonfire cookoff test provided fragment mapping and confirmed the release of a DU aerosol. The first report occurred 3 min 15 s into the test when indicated temperature had reached 750 to 800°C at the periphery of the stacked ammunition cases. Reports ceased about 16 min later. All fragments remained within 400 ft of the bonfire.

Seven DU penetrators underwent visually detectable mass loss due to high temperature exposure in the bonfire. Fewer penetrators lost visually detectable amounts of DU in this test than in the 1975 test. DU aerosol detected by high-volume air samplers was also lower than the 1975 result.

The sympathetic detonation test indicated that none of the other HEI rounds in the container detonated sympathetically.

ACKNOWLEDGMENTS

Our appreciation for their contribution to the completion of these tests is extended to: L. M. Baggett, J. M. Greene, J. Armstrong, L. Buettner, and F. Cartwright, all M-4; K. D. Carter and P. E. Trujillo, H-5; W. E. Clements, S. K. Wilson, and K. H. Rea, H-8; G. W. Heinze, SP-4; J. R. Caldwell, Zia Company; I. F. Farrar, Eng-4; F. J. Southard, E-1; B. R. Claybrook and J. M. Ulibarri, ISD-7; R. J. Alarid and L. Salazar, Eng-1., We also thank R. Oates, F. L. West, and J. Cornette, AFATL, for their cooperation in organizing the test and direct help in pattern scoring and live explosive handling.

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